APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: INTERFEROMETRIC SYSTEM FOR PRECISION IMAGING OF
VIBRATING STRUCTURES

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INTERFEROMETRIC SYSTEM FOR
PRECISION IMAGING OF VIBRATING STRUCTURES

Cross Reference To Related Applications

This application claims priority from Provisional Application U.S.

5.   Serial No. 60/074,902, filed February 17, 1998.

Statement as to Federally Sponsored Research

The invention described herein was made in the performance

of work under a NASA contract, and is subject to the provisions

of Public Law 96-517 (35 U.S.C. 202) in which the Contractor has

10   elected to retain title.

Background of the Invention

It is often desirable to quantitatively measure the motion

of a structure. This can be carried out using various

instruments. A particularly useful family of said instruments

15   uses optical techniques.

US Patent No. 4,619,529, issued 10/28/86, "Interferometric

contact-free measuring method for sensing motional surface

deformation of workpiece subjected to ultrasonic wave vibration",

teaches a method for observing sound waves on a workpiece by

20   interfering two beams that are reflected from different points on

the workpiece. The pulsing relates to the pulsed laser beam that

-1-

generates the sound waves on the workpiece. The interferometer beams are not pulsed.

US Patents No. 3,572,936, issued 03/30/71, "Stroboscopic Interferometric Holography", and No. 4,999,681, issued 03/12/91, "Real-time holographic interferometry with a pulsed laser and flicker-free viewing", teach two methods for producing a hologram of a vibrating object by using stroboscopic illumination. The motion is determined from the generation of a second reference hologram of the rotated object or the object at rest. The second hologram is produced as a second image of the first hologram to produce a interference that determines the motion.

A publication by O. Kwon et al, Opt Lett 12: (11) 855-857 Nov 1987, teaches a method of pulsed source interferometry. A conventional interferometer is equipped with a Q-switched Nd:YAG laser which is capable of generating high intensity pulses. This is necessary since the authors use only a single pulse to record the interferometric fringe pattern with a camera. The limitation to using a single pulse is overcome by the use of a grating to generate three interferograms which are acquired simultaneously by three cameras. In addition two gratings are used to generate the required phase shifts, restricting the source to be monochromatic due to the inherent chromatic dispersion of a grating.

A publication by S Nakadate et al.,Opt Acta 33: (10) 1295-1309 Oct 1986, teaches holographic interferometry. There

3

are many other systems which do the same. In these methods, the contours of vibration amplitude are given as a fringe pattern.

One particularly useful device is based on optical interference using, e.g., a Michaelson Interferometer.

5   For example, an optical profiler is available from the company WYKO, under the name of WYKO RST Plus Optical Profiler. This is a scanning imaging white light interferometer. A block diagram of the device has the structure shown in FIG. 1. An incandescent light source 100 is focused through lens 102 to half

10   mirror 104. The light is reflected down to a microscope 110. The light passes through microscope objective 112, to a beam splitter 114. The beam splitter 114 produces a reference beam 116 that is reflected to eventually recombine with the reflected object beam.

       The object beam 118 passes to the object being imaged at

15   120, and is reflected. This beam then recombines with the -- -- reference beam 116, to produce an interference. A CCD video camera 125 images the operation. This system has the ability to detect minute features on the surface of the sample 99.

20   Summary of the Invention

The present inventors recognized that this instrument as configured is capable of analyzing only stationary structures.

Any vibration on the sample blurs the interference pattern. This prevents the sample from being accurately analyzed.

The present disclosure teaches an instrument that allows interferometric detection of moving structures. This is done by

5   pulsing the output.

According to the present system, the optical profiler is modified to allow it to image certain vibrating structures, and specifically microelectrical machined (MEMS) devices.

The present disclosure teaches a method and an instrument

10   for determining periodic motion of structures, specifically micromachined structures. The instrument is an imaging interferometer equipped with a pulsed illumination source. The illumination source is pulsed synchronously and with a predetermined relationship to the motion of the structure thus

15   immobilizing what would otherwise be a rapidly changing interference pattern which is imaged by a camera.

In a preferred mode, every frame output by a camera represents an average (integral) of interference patterns during multiple cycles of object motion. The interference pattern images

20   are acquired and processed to recover the modeshape - the "picture of the motion" of the structure.

Brief Description of the Drawings

These and other aspects will be described in detail with respect to the accompanying, wherein:

5   FIG. 1 shows a diagram of the prior art optical profiler; and

FIG. 2 shows a modified instrument including improved structure for imaging moving devices.

Description of the Preferred Embodiments

10   FIG. 2 shows the modified device. The light source in this device is preferably a light source with low thermal inertia that can be modulated at rates higher that 10KHz, and preferably higher than 1MHz. A preferred light source is an ultrabright, light emitting diode ("LED"), which produces 0.05 watts of

15   output. This LED can be turned on and off at rates up to about 2 MHZ.

A pulse generator 210 is provided which produces a pulse output that modulates the LED.

The system described herein also is used to detect

20   movements, e.g. vibrations, of micromachined structure 199. The micromachined structure 199 is driven to vibrate. The driving is preferably done by a signal generator that drives the pulse

generator that drives the LED. A phase offset, shown as ∅, exists between the two outputs 202 which drives the LED and 204 which drives the micromachined structure 199. This phase offset can be used to change the point in the vibration cycle of the

5 micromachined device 199 at which the visual image is acquired.

The visual image is acquired by driving the LED to produce strobes of light. Each pulse of the LED strobe illuminates both the object to be imaged and the reference surface. The interference between the two illuminations enables determination

10 of position. Since the pulse of the strobe is short, the device, even if moving, will not have moved much during the strobe. This avoids blurring of the interferometric measurement.

In a particularly preferred embodiment, the MEMS device which is imaged is a cloverleaf-type rotary vibration sensor.

15 The inventors also found that many MEMS devices, including the one that is preferably imaged herein, vibrates differently under atmospheric pressure or might not vibrate at all under such pressure. This can be caused by excessive viscous drag on the micromachined structure. Accordingly, the operation of the

20 present system includes a vacuum chamber 230 provided to house the sample. The vacuum chamber includes a vacuum port 232 connected to a vacuum source 234. The vacuum source evacuates the air from the chamber 230. The MEMS device 199 to be detected is located in the chamber 230. The vacuum chamber 230 also

-6-

7

includes a wire port 236 allowing wires to be connected so that the signal generator 210 can vibrate and/or actuate the MEMS device 199.

The sample beam 120 in this embodiment therefore encounters an additional glass plate: the viewport 238. In order to compensate for the effects of the viewport, a compensating plate 240 is placed into the reference arm 242 of the Michelson interferometer. The compensating plate is of the same thickness as the glass viewport 238. This compensates for the extra glass in the path caused by the vacuum chamber.

In order to accurately detect the movement of the MEMS device 199, it is necessary to modulate the light source at a synchronized modulation rate, that is synchronized to the movement of the MEMS device 199. Movement of the device during the illumination pulse could cause blurring of the fringe of the interference pattern. Therefore, the duty cycle of the source should be shortened as the vibration amplitude increases. The device should not move more than a distance of about 1/20th of the center wavelength of the source, during the illumination pulse. Hence, for a structure vibrating at 10 kHz with a 10 μm amplitude, this translates into a maximum pulse width of about 200 nsec, or about a 0.2% maximum duty cycle. The overall integrated light intensity of a frame using illumination with such a short duty cycle may be very small.

The pulse rate of the light source should be at least a factor of 10 lower than the lowest modulation rate of the light source. As explained above, the light source must be modulable at least at 10 Khz.

5   If the amount of incoming light is too small, or to improve the noise, the system can integrate over a larger number of periods. Presumably, the image obtained during each period is substantially the same. Hence, by integrating a number of these images, the light output can be increased.

10   A processor calculates the relationship between the interference fringes, and uses that to determine the position of the device. This is done in a conventional way. The phase between motion and light pulse can be varied to image the device at different points in its periodic motion. The processor then

15   calculates all of these different positions.

Superluminescent LEDs, a cluster of conventional LEDs, or a laser could be used to further improve the brightness.

Although only a few embodiments have been disclosed in detail above, those of ordinary skill in the art should certainly

20   understand that modifications are possible in the preferred embodiment without departing from the teachings hereof. All predictable modifications are intended to be included. For example, while the present system describes only modifying a single optical profiler, it should be understood that other

-8-

optical profilers can also be modified. For example, any optical

profiler which uses an imaging interferometer could be modified

in this way. More generally, however, any measurement detecting

structure which detects using optical operations could be

5   detected in this way.

The operation describes using a single pulse generator, but

of course two separate pulse generators could be used, with one

triggered from the other.

Moreover, the system herein describes using a

10   superluminescent LED as the light source. However, any light

source which can be modulated at a high enough rate can be used.

All such modifications are intended to be encompassed within

the following claims in which: